How Does a Change in Initial Velocity Affect the Stopping Distance of a Cart?

Introduction

In this assessment I am going to investigate the effect that increasing the initial velocity of a cart has upon its stopping distance. The reason I chose this topic is because I ride a motorcycle and wished to investigate braking and stopping distances as I experience them every time I ride, it is due this that I have particular interest in this topic. The independent variable in this investigation is the initial velocity, and the dependent variable is the stopping distance. Other constant variables are the coefficient of friction between the cart and the surface and the mass of the cart.

Thus the question to be answered here is whether changing the initial velocity will have an effect on the stopping distance. My prediction is that the higher the initial velocity, the further the vehicle will travel before stopping.

Design

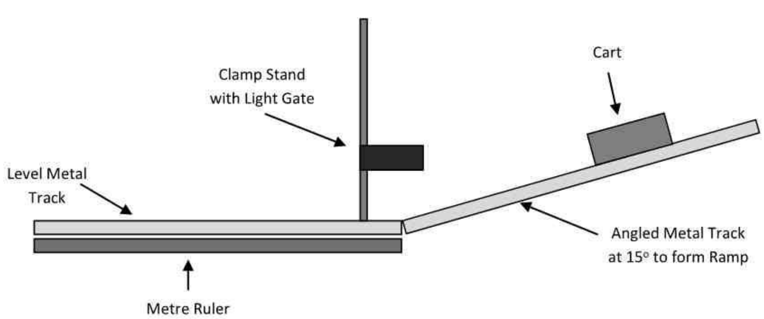
Equipment List:

- Metal Tracks x2
- Cart with picket fence card
- Light Gate and Data Collector
- 100g mass
- Clamp Stand
- Ruler

The data collection system used was a Pasco 750 connected to a desktop computer running Data Studio and the light gate is a standard Pasco light gate calibrated for use with a picket fence card. The data will then be transferred into a spreadsheet program and then into a piece of graphing software. The metal tracks are standard Pasco aluminium 1 metre tracks and the cart used is a Pasco low friction cart.

Method:

To find the values for both variables I will arrange the equipment in accordance with the following diagram.



Initially I will position the ramp and secure it an angle of 15 degrees, after doing this I will ensure that the two tracks are connected as tightly as possible and position the light gate. Then using the measurements marked on the ramp I will position the cart at increasingly elevated positions at intervals of 10cm. At each of these intervals I will release the cart and measure the initial velocity with the light gate and then measure the stopping distance of the cart on the flat section with the ruler once it has come to a standstill. The stopping distance is defined as the distance from the end of the angled ramp, to the back of the cart once it has stopped. The metre rule is positioned parallel to the track and is perfectly aligned with the end of the flat track section to avoid any zero errors. I will repeat each measurement 3 times and take the mean value from the 3 repeats. I am going to take out 9 measurements at different positions up the ramp.

Background Theory

The cart accelerates down the ramp due to the gravitational force acting upon it. When elevated further up the ramp the cart gains gravitational potential energy as shown by the equation $E_p = mgh$. As the cart travels down the ramp its gravitational potential energy is converted into kinetic energy which causes its velocity to increase. When the cart leaves the ramp all of its gravitational potential has been converted into kinetic energy which is all converted to heat and sound energy as the cart comes to a stop, this energy conversion is due to the friction between the cart and the track.

The background theory states that the higher the cart starts on the ramp, the higher its gravitational potential will be thus the more kinetic energy it will have as it leaves the ramp. If the cart possesses more kinetic energy it will take longer to be converted into heat and sound energy and thus will take longer to stop.

We can also further understand the velocity of the cart by referring to the following suvat equation:

$$v^2 = u^2 + 2as$$

(v = final velocity of cart   u = initial velocity of cart   a = acceleration of cart   s = stopping distance)

Using this equation and rearranging it produces the conclusion that the value of initial velocity squared is proportional to the stopping distance of the vehicle.

$$u^2 = v^2 - 2as$$

Accuracy

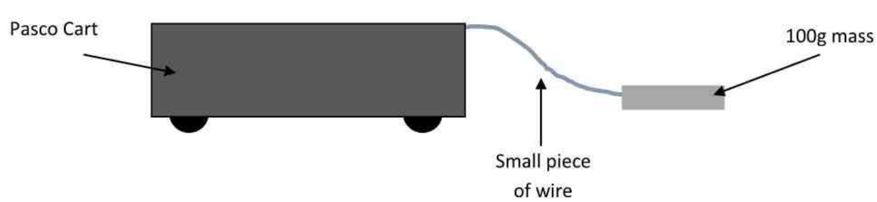
To increase the accuracy of my experiment I will use the same cart for all of my measurements. By doing this the friction of the bearings in the cart should be the same for all repeats. I will also make sure the ramp is at the same angle for all measurements as a different gradient would cause the cart to have a different acceleration and thus change the initial velocity.

Furthermore I will ensure that the light gate is in the same position for all measurements as measuring the initial velocity at a different location could cause inaccuracy. I will also check that the metre rule is correctly positioned before measuring the stopping distance to avoid any zero errors.

Improvements to Method

Initially I was going to use Pasco motion sensors to find a value for initial velocity, however I adapted my method and decided to use light gates instead as with the picket fence card setup the light gates produce very accurate data. I thought that they would be more accurate than the motion sensors as the light gates are more suited to measuring objects passing perpendicular to them whereas the motion sensors are more suited to objects moving directly towards and away from them, thus for my experiment the light gate is a better choice as the cart is passing perpendicular to it.

Initially I attempted to explore the relationship between initial velocity and stopping distance with an unmodified cart, however due to the low friction of the bearings in the wheels of the Pasco cart, it travelled a great distance after leaving the ramp and thus I did not have enough space to investigate the relationship in this manner. After discovering this I decided the only way to continue my exploration was to increase the friction of the cart on the ramp. I did this by attaching a 100g mass with a small piece of wire to the back of the cart. This was very effective as the increased friction given by the 100g mass being in contact with the metal track caused the cart to stop within the metre length of the level track. I was concerned at first that this would make the test unfair however there is still a constant coefficient of friction between the two materials thus the investigation is exactly the same, the friction is just higher. This made measuring the stopping distance much easier. The setup of the cart is shown clearly in the following diagram.



Uncontrollable Factors

One factor that I could not control was a small bump between the ramp and the level track. I was made aware of this by a small but sudden decrease and increase in the acceleration of the cart as it passed between the two tracks. I tried a range of methods to reduce this including placing small pieces of tape to smooth the join and changing the angle of the angled track but unfortunately I could not remove it completely. I assume that as the cart passed over the bump there was a small frictional force causing the cart to decelerate slightly. I tried to find the magnitude of this frictional force by pulling the cart over the bump with a Newton metre, however when combining the value collected from the Newton metre with the F=ma equation the force was around 500N which is far too large. I decided that even with the bump in the track the relationship was still clearly visible so I continued the investigation.

Safety Concerns

In this investigation there were little to no reasons to be concerned about safety. The cart has very little mass and stopped within 1 metre so the chance of collision with anyone was extremely low. Other than this I can see no other potential safety issues.

Data Analysis

Shown below is the table including all the data collected over the three repeats for both initial velocity and stopping distance with their respective mean values. The start position on the left of the table is not relevant for the data, it was simply a method I used to measure the distance up the track from where I released the cart.

		Initial Velocity (ms^{-1}) +-0.01				Stopping Distance (m) +-0.06		
Start Position	1	2	3	mean	1	2	3	mean
30	1.45	1.40	1.45	1.43	0.126	0.104	0.124	0.118
40	1.97	1.97	2.05	2.00	0.208	0.213	0.253	0.225
50	2.39	2.45	2.42	2.42	0.310	0.364	0.332	0.335
60	2.70	2.64	2.75	2.70	0.428	0.398	0.407	0.411
70	2.90	2.88	2.88	2.89	0.582	0.538	0.553	0.558
80	3.16	3.18	3.16	3.17	0.559	0.621	0.608	0.596
90	3.52	3.50	3.49	3.50	0.751	0.727	0.680	0.719
100	3.70	3.74	3.74	3.73	0.776	0.804	0.824	0.801
110	3.91	4.00	4.00	3.97	0.806	0.885	0.866	0.852

Absolute error values deduced by taking the maximum and minimum values from the repetitions and then dividing them by two then dividing by the mean as shown below.

Errors Initial Velocity (ms^{-1})
0.02
0.02
0.01
0.02
0.003
0.003
0.004
0.005
0.01

To find the absolute errors for all the data I took the means of the error values as there was a range.
Mean IV: 0.01 (ms^{-1})
Mean SD: 0.06 (m)

Errors Stopping Distance (m)
0.09
0.1
0.08
0.07
0.04
0.06
0.05
0.03
0.04

Error Calculations

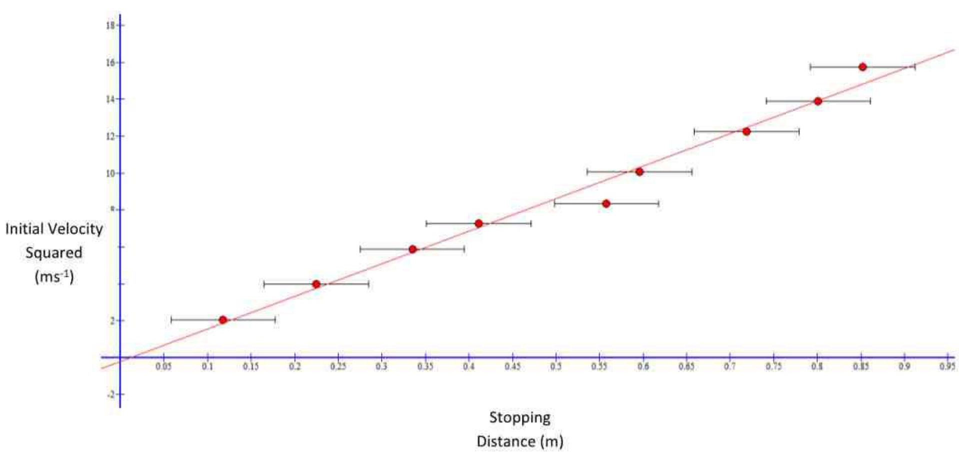
Initial Velocity Example:

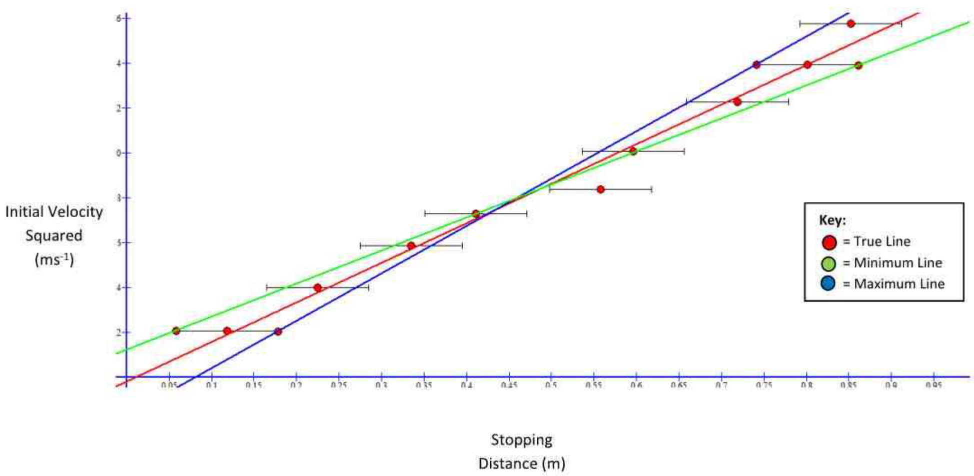
2.05 - 1.97 = 0.08
0.08/2 = 0.04
0.04/2.00 (mean value) = 0.02
0.02 x 100 = 2 => 2% error
2% + 2% = 4% (due to u^2 on y-axis)

Stopping Distance Example:

0.124 - 0.104 = 0.02
0.02/2 = 0.01
0.011/0.118 = 0.084746
0.084746 x 100 = 8.476 => 8.5% error

However, after calculating these errors and using them to produce errors bars on my graph I found that in two cases the line of best fit did not pass through the calculated error bars. This data was obviously under the influence of a random error as the points are sat quite far from the line of best fit.

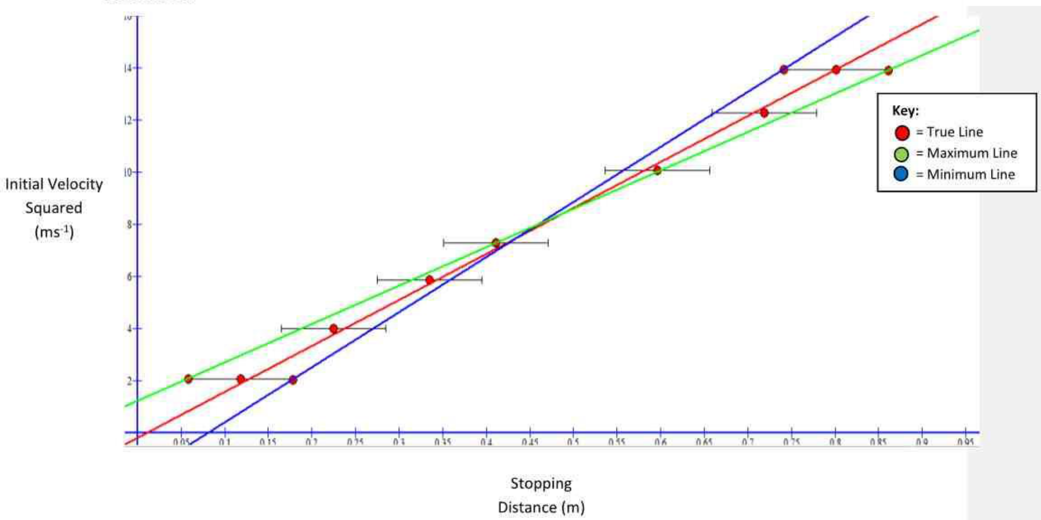




Shown above is the graph with the maximum and minimum lines plotted. Although convention states that the line should be produced by using the lowest and highest points, on my graph the highest point is an outlying value and caused the max and min lines to lie outside of the error bars for the rest of the data. To combat this I used the second highest point instead which produced a far better maximum line. In this case the highest value should be ignored as it does not follow the trend suggested by the rest of the data. I thus decided to remove these two points as they do not obey the law that the rest of the points abide with. Shown below is the final graph.

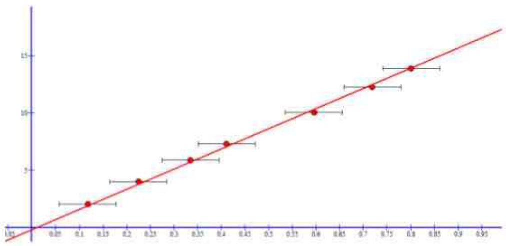
The points on the graph also have extremely small vertical error bars. This is due to the fact that the error value for the light gate is extremely small because it is a very accurate measuring device.

Evaluation



Conclusion:

The conclusion suggested by this investigation is that the value of initial velocity squared is proportional to the stopping distance, as was stated by the theory. The clear justification for this is the positive constant gradient of the graph when initial velocity squared is plotted against stopping distance.



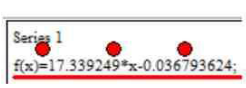
Although the y intercept of the line of best fit did not intercept at (0,0) as was suggested by the background theory. The incorrect value is most likely due to a systematic error which caused the intercept to be (0.00212,0). However, the value is so close to the expected value so it is no of concern to me and does not suggest a poor method.

There are two outlying values in the data which could have been caused by changes of friction on the track or by me releasing the cart in a different way, possibly applying a different amount of force to it. These items of data are obviously anomalies as the line of best fit lies outside their error bars. If I was to redo the experiment I would ensure that unsuccessful repetitions similar to these were revisited. However, although the two anomalies do not suit the line of best fit they do still support the general positive correlation of the graph.

The gradient of the graph should be equal to negative two multiplied by the acceleration of the cart. This is shown using the following rearrangement:

$$y = mx + c$$
$$y = 17.34x + 0.00212$$
$$v^2 = u^2 + 2as$$
$$u^2 = v^2 - 2as$$

As initial velocity squared (u^2) is plotted on the y-axis and stopping distance (s) is plotted on the x-axis it can be deduced that -2a is equal to the gradient (m). Using this I found that the deceleration of the cart was 8.65ms^{-2}.



As shown by the key from the graphing software the gradient of the line is 17.3 .

17.3 = -2a => 17.3/2 = a = 8.65

With more time I would have repeated the trials that produced outlying values so that they were more congruent with the line of best fit. I feel that this would've greatly improved the investigation.

Also it would have been far easier if the cart had had slightly more friction so that it would have stopped within the track without the extra modification of the 100g mass. I feel that this would've improved the accuracy of my results as there would be less variability in the coefficient of friction whereas in the method I used the mass could've been in different positions where it had more or less friction, these could've been a factor that produced my anomalous values. Also I could have used a more accurate measuring system than the metre ruler. A suitable alternative could have been a motion sensor calibrated to measure distance.

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4/ICCS

Group 4: Individual candidate cover sheet (biology, chemistry and physics)

Arrival date: **20 April / 20 October**

Session: May 2016

School number:

School name:

- *Complete this form in the working language of your school (English, French, Spanish).*
- *The form must be completed by the teacher and candidate.*
- *A completed copy should be retained by the school.*

Subject: Physics

Level: HL

Candidate name:

Session number:

Candidate section:

To be completed by the candidate.

Title of the group 4 project: Out of this world

Write a reflective statement of about 50 words outlining your involvement in the group 4 project:

My team name was supernatural and we were investigating real life phenomenon that exceed the normalities of nature. In my group we did an experiment testing the magnetic field strength of different type of magnets to see which was the strongest. We found that the alcomax and neodymium magnets were the strongest however the alcomax magnet had a much greater surface area and thus was able to lift much greater mass than the neodymium. We a magnetic field strength sensor however the highest value that it would read was 1 Tesla which was not high enough to measure the alcomax or the neodymium.

Title of individual investigation: How Does a Change in Initial Velocity Affect the Stopping Distance of a Cart?

Candidate declaration: I confirm that this investigation is my own work and is the final version. I have acknowledged each use of words or ideas of another person, whether written, oral or visual.

Candidate's signature:

Date: 28/2/16

Please turn over